The path to ignition on the National Ignition Facility

Presentation to
Workshop on Nuclear Astrophysics at the National Ignition Facility

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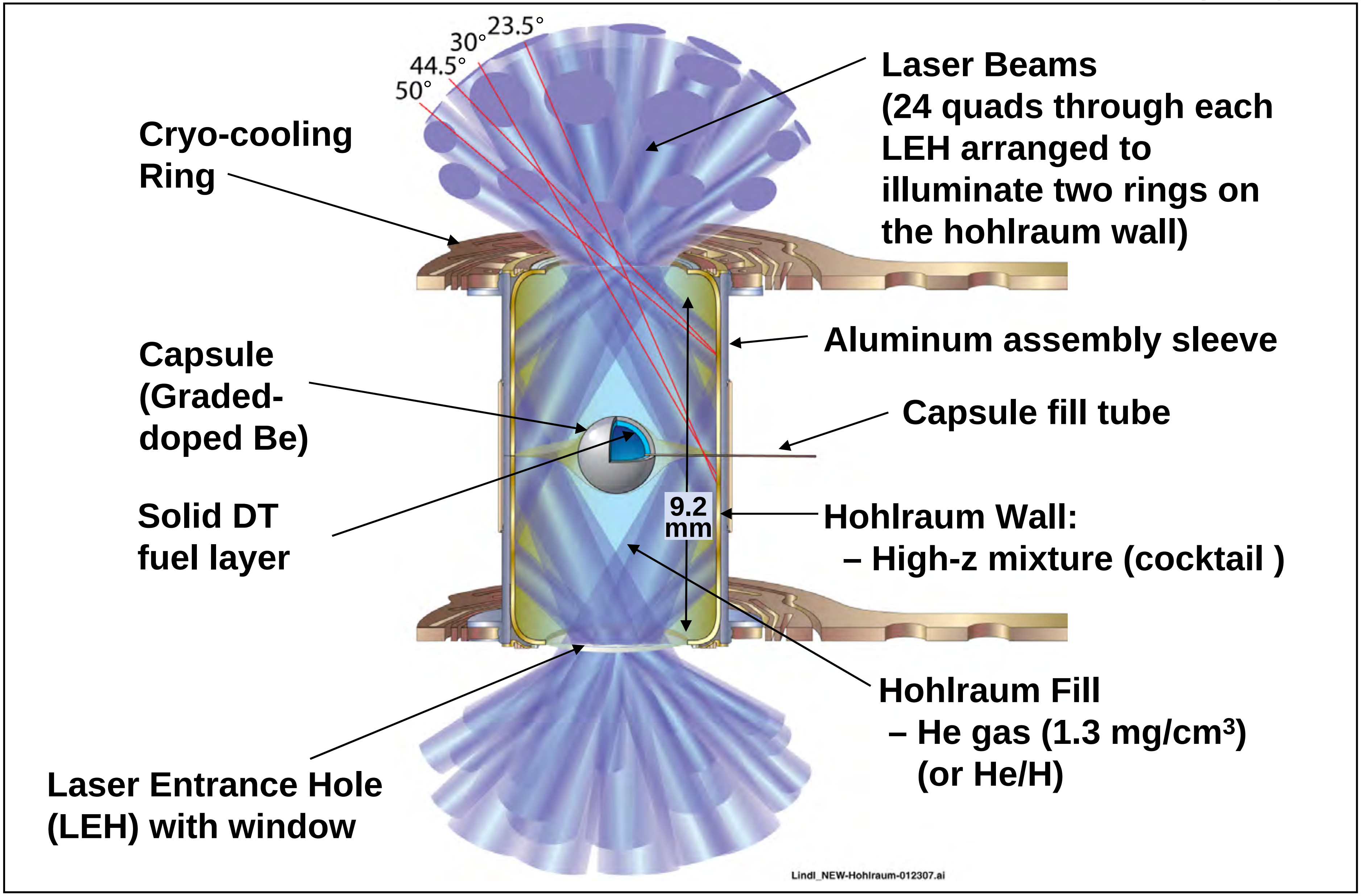
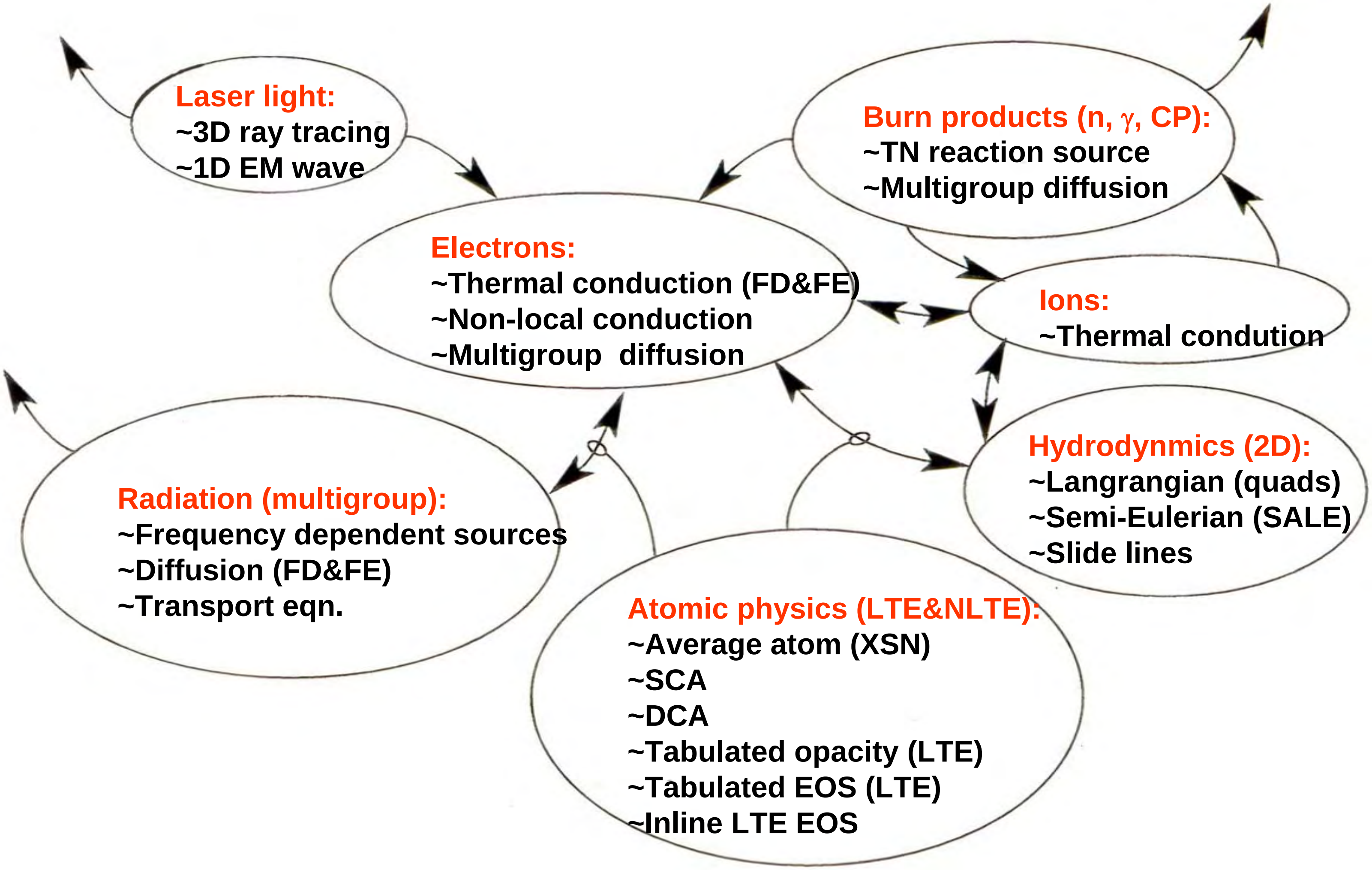
After 15 years, all of the pieces for ignition are almost in place

- **The NIF laser and the equipment needed for ignition experiments, including high quality targets, will be available in 24 months**
- **We have an ignition point design target near 1 MJ with a credible chance for ignition during early NIF operations**
- **The Laser Plasma Interaction (LPI) uncertainty for the first ignition experiments is bounded by ignition designs from about 1-1.3 MJ in laser energy or by a range of hohlraum temperatures from 270-300 eV**
- **We have an Early Opportunity Shots (EOS) campaign with 96 beams planned to start within the next year which will allow us to choose the optimum hohlraum temperature and laser energy for initial ignition experiments.**
- **The initial ignition experiments only scratch the surface of NIF's potential which includes high yields with green light and greatly expanded opportunities for the uses of ignition by decoupling compression and ignition in Fast Ignition (FI).**

The NIF point design has a graded-doped, beryllium capsule in a $U_{0.75}Au_{.25}$ hohlraum driven at 300 eV



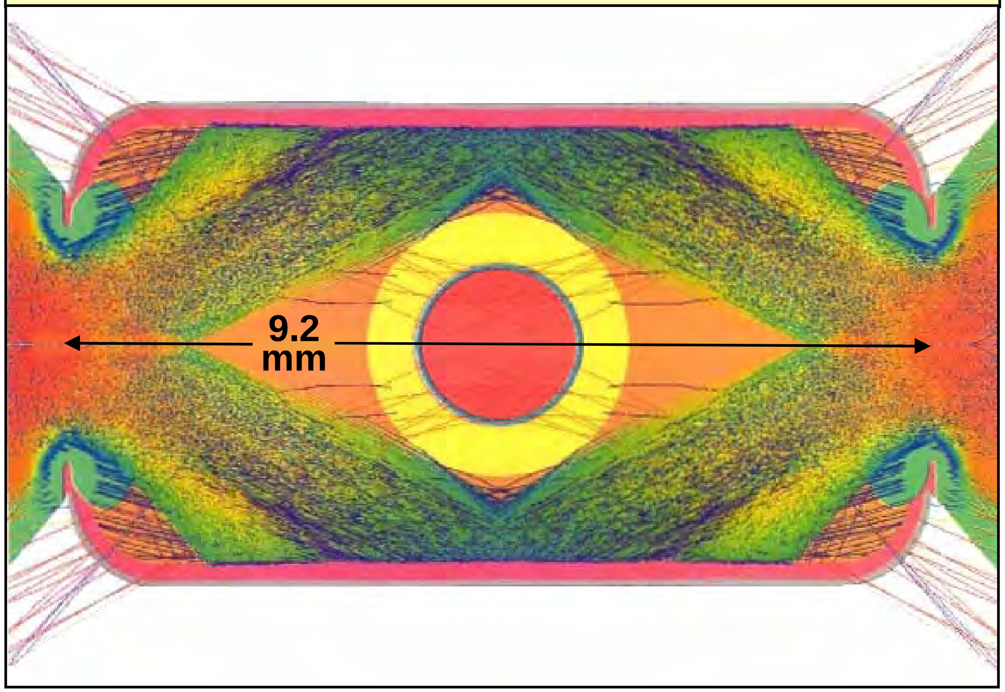
Lasnex/Hydra are versatile computer codes for modeling ICF implosions



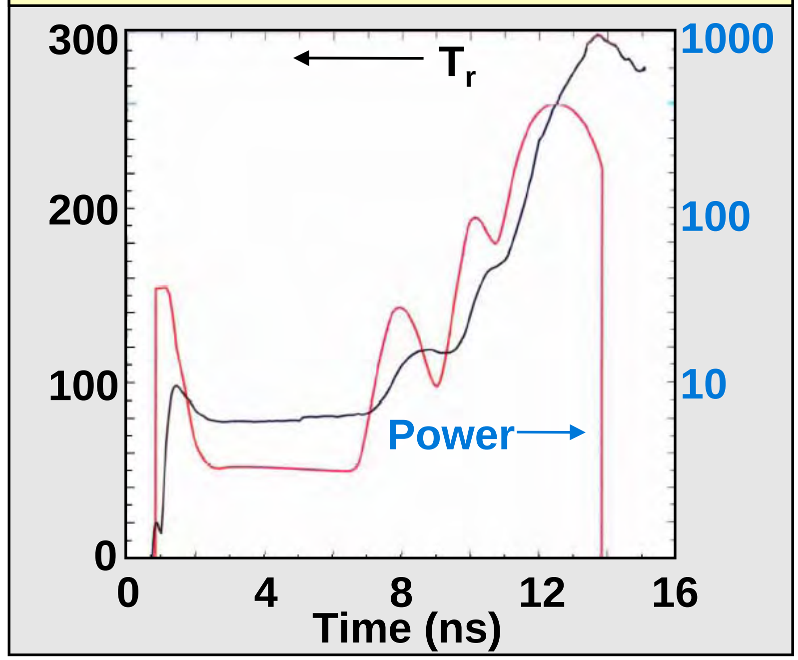
- Lasnex is 1D and 2D, Hydra is 1D, 2D, and 3D
- Laser Plasma Interaction (LPI) effects are only included as boundary conditions (detailed modeling of LPI is done in separate codes which are not able to model the full scale ignition plasma in space or time)

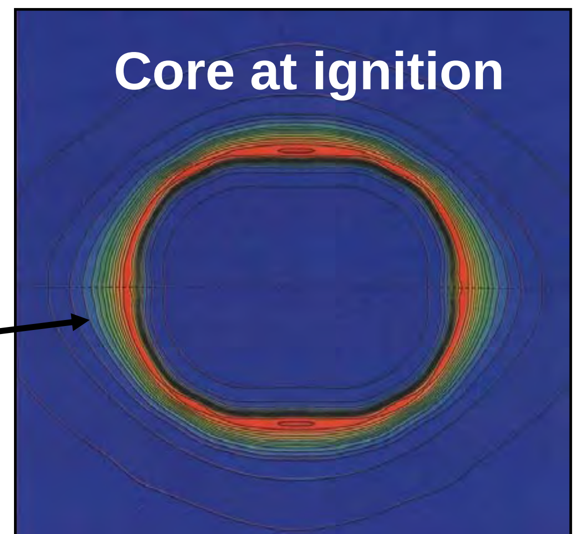
Optimized Lasnex 2D symmetry calculations meet the point design requirements

Beam spots are as large as possible consistent with LEH clipping and symmetry control



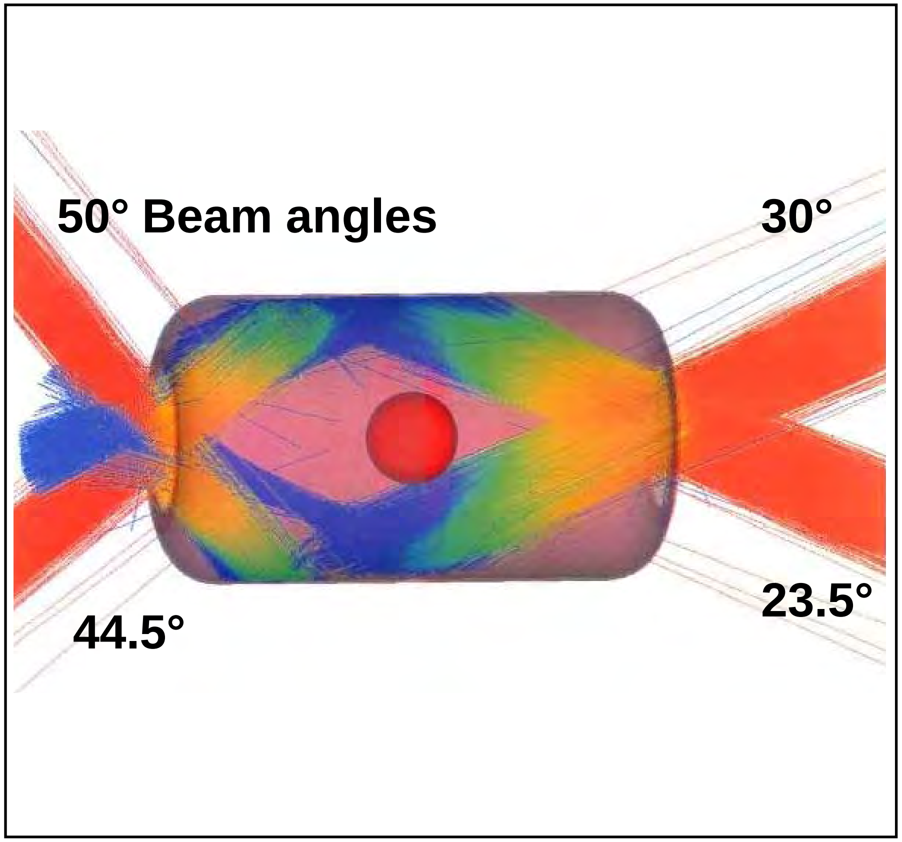
Power (TW) and T_r (eV)



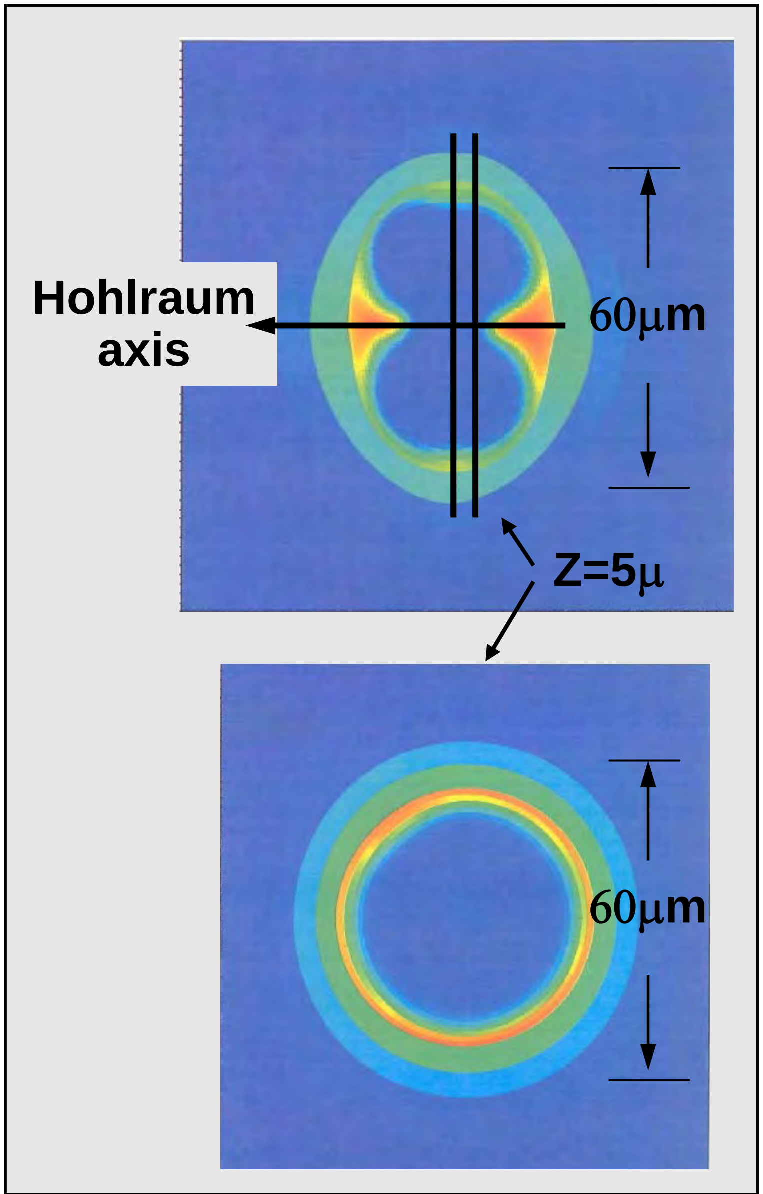


The imploded fuel core shows very little residual angular variation from the NIF multi-cone geometry

Initial calculations with Hydra of the 300 eV point design show very little 3D azimuthal asymmetry



- The 2D implosion had not been optimized for this 3D implosion
- We will soon be doing 3D calculations to assess the impact of power balance and pointing errors



Cross section perpendicular to the hohlraum axis

We have a point design for ignition that is under configuration control by the National Ignition Campaign(NIC) program

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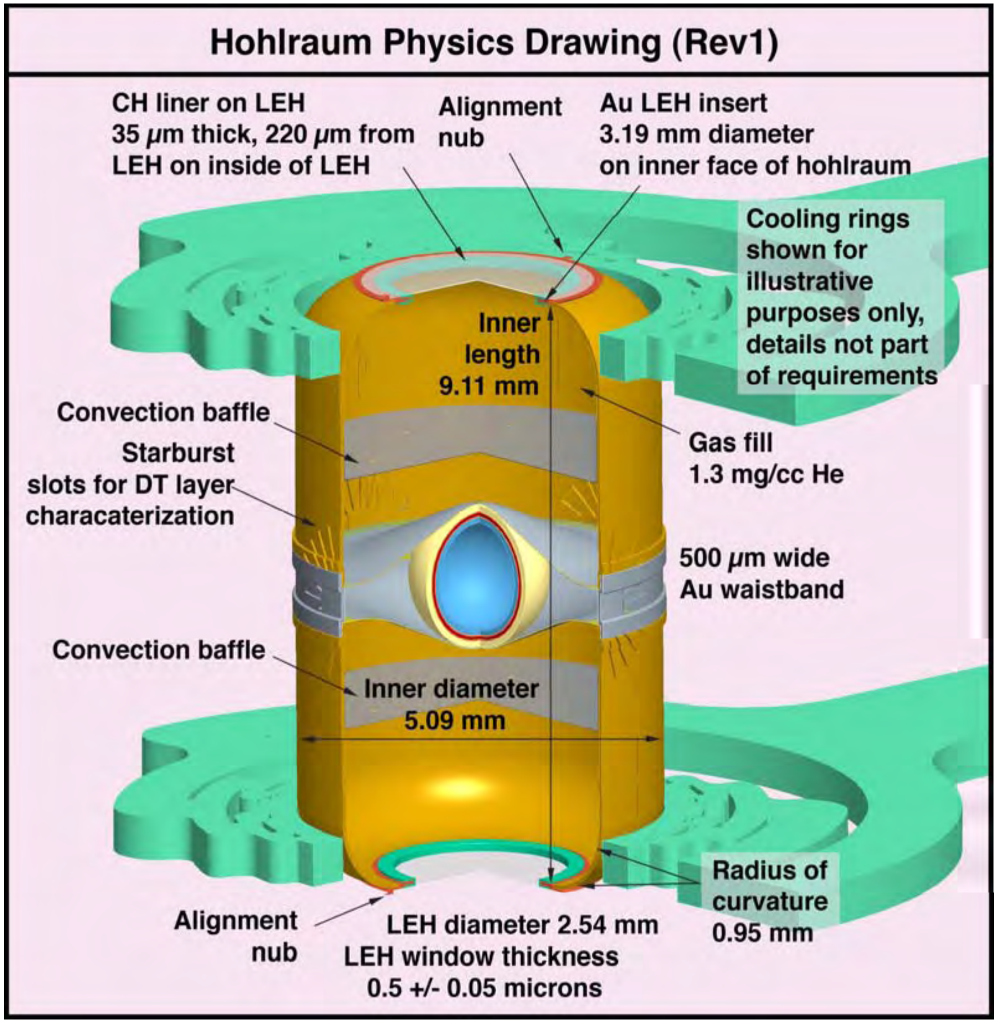

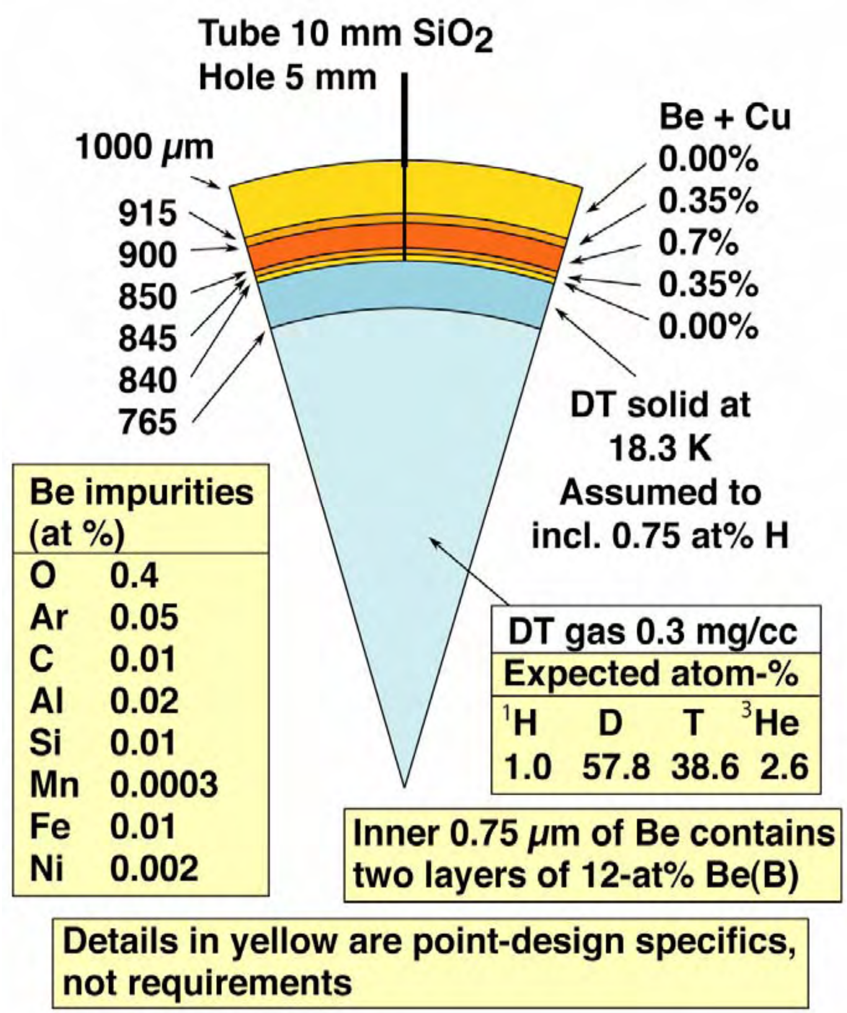

We perform multivariable Monte-Carlo scans to quantify the distribution of yields expected for the point design capsule

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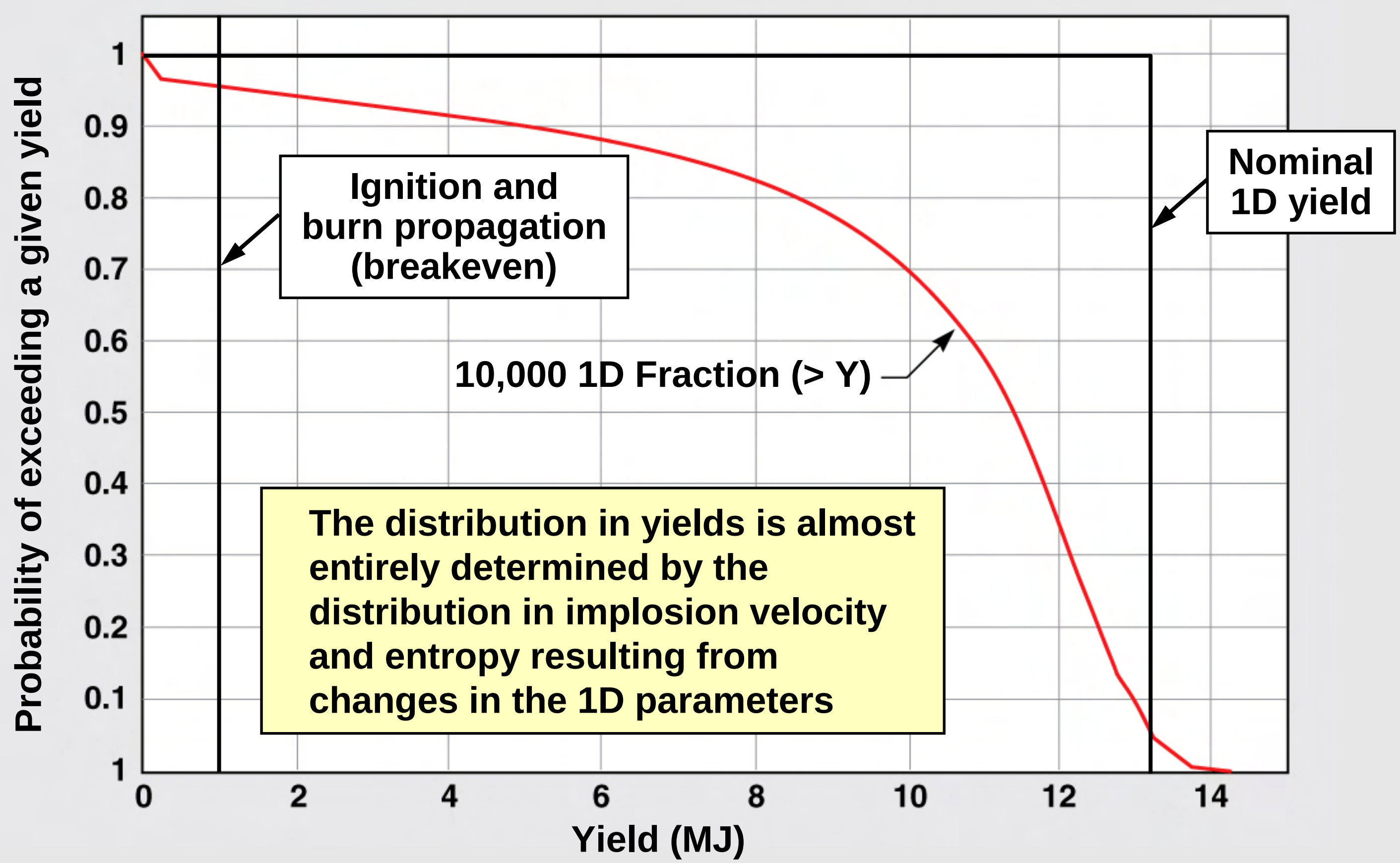
10,000 simulations varying 33 1D parameters meeting specifications for the capsule, hohlraum, laser, and experimental tuning for the 300 eV baseline capsule



We are starting to incorporate the impact of 2D and 3D perturbations on the expected capsule performance

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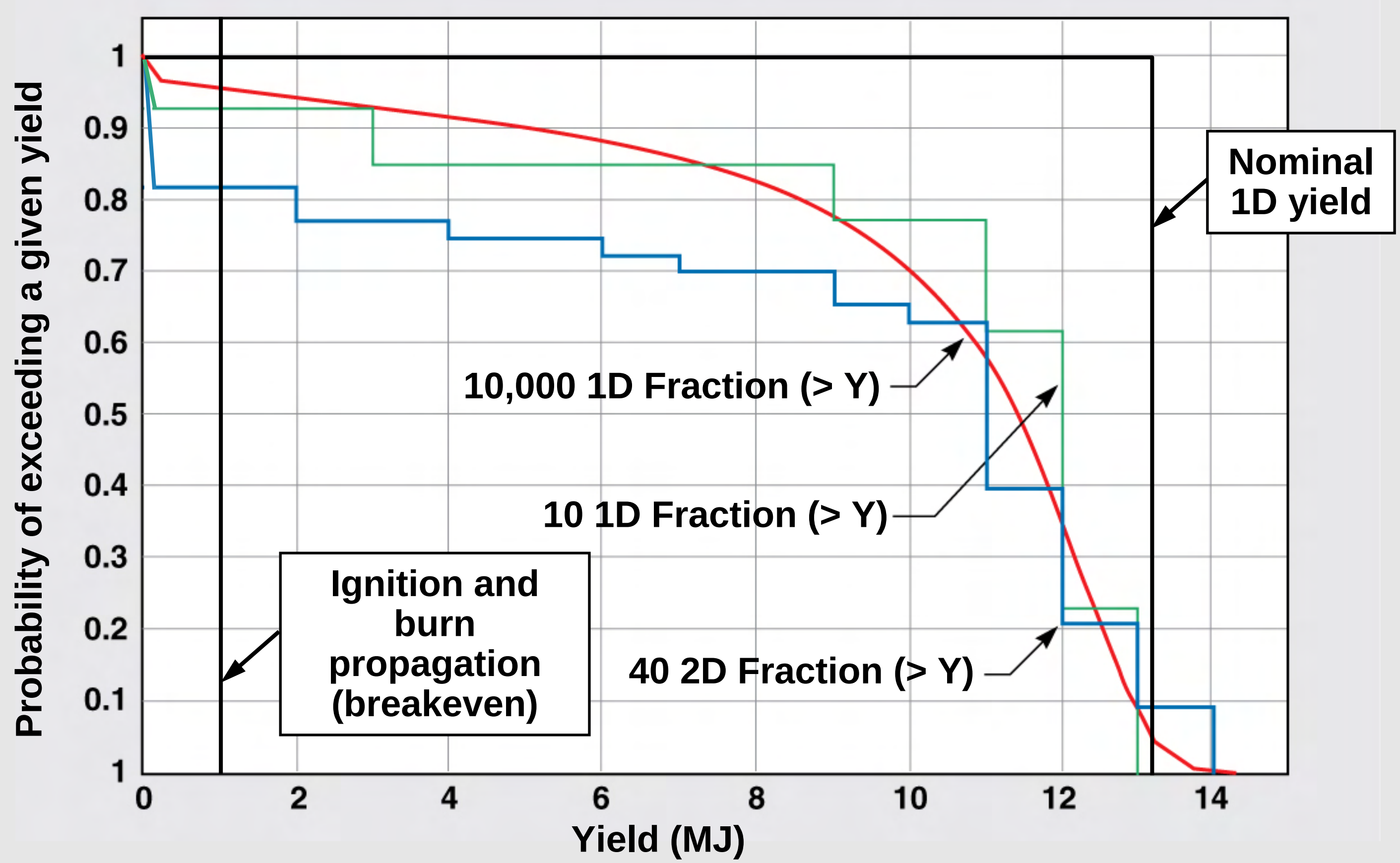
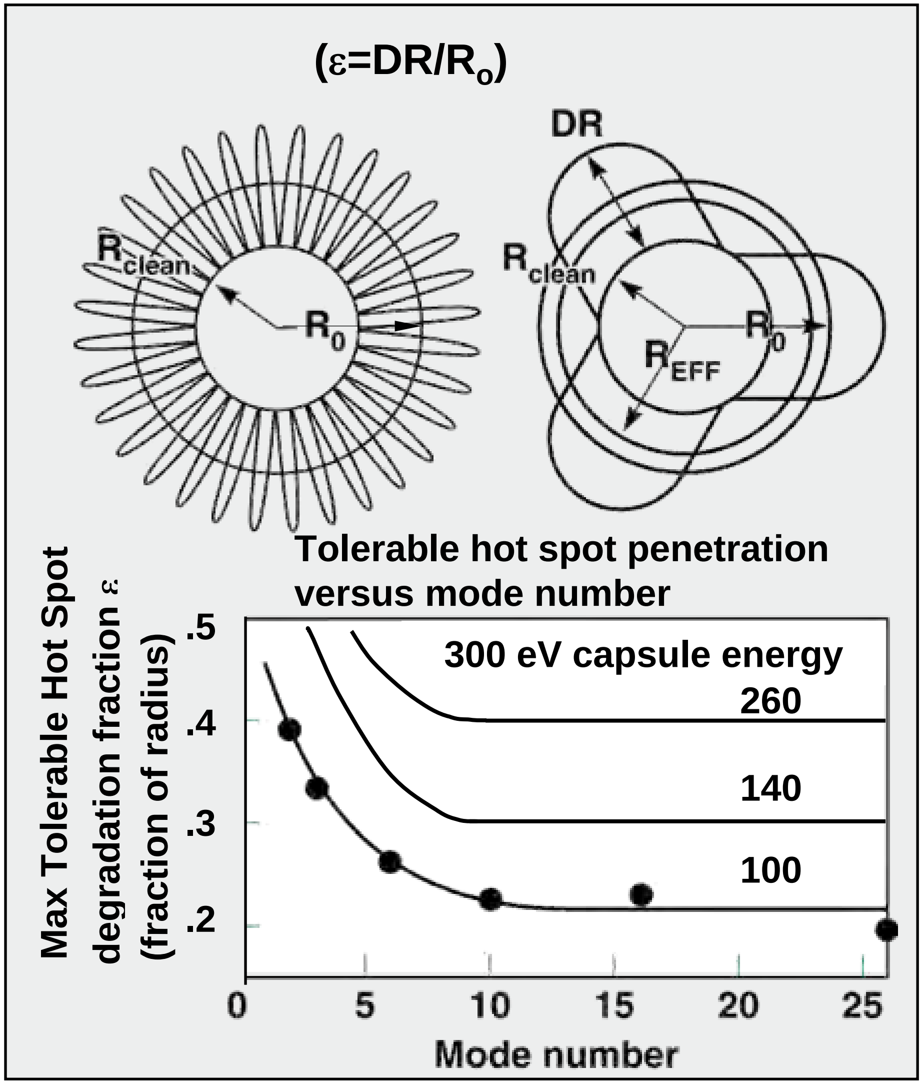
The 2D calculations have nominal perturbations on all 7 capsule surfaces (run 4 times with random phases), using 10 sample 1D simulations from the initial set of 10,000



Hohlraum asymmetry is the largest perturbation missing from these calculations — to be added soon

The impact of most 3D effects that degrade an implosion can be specified as a hot spot degradation fraction



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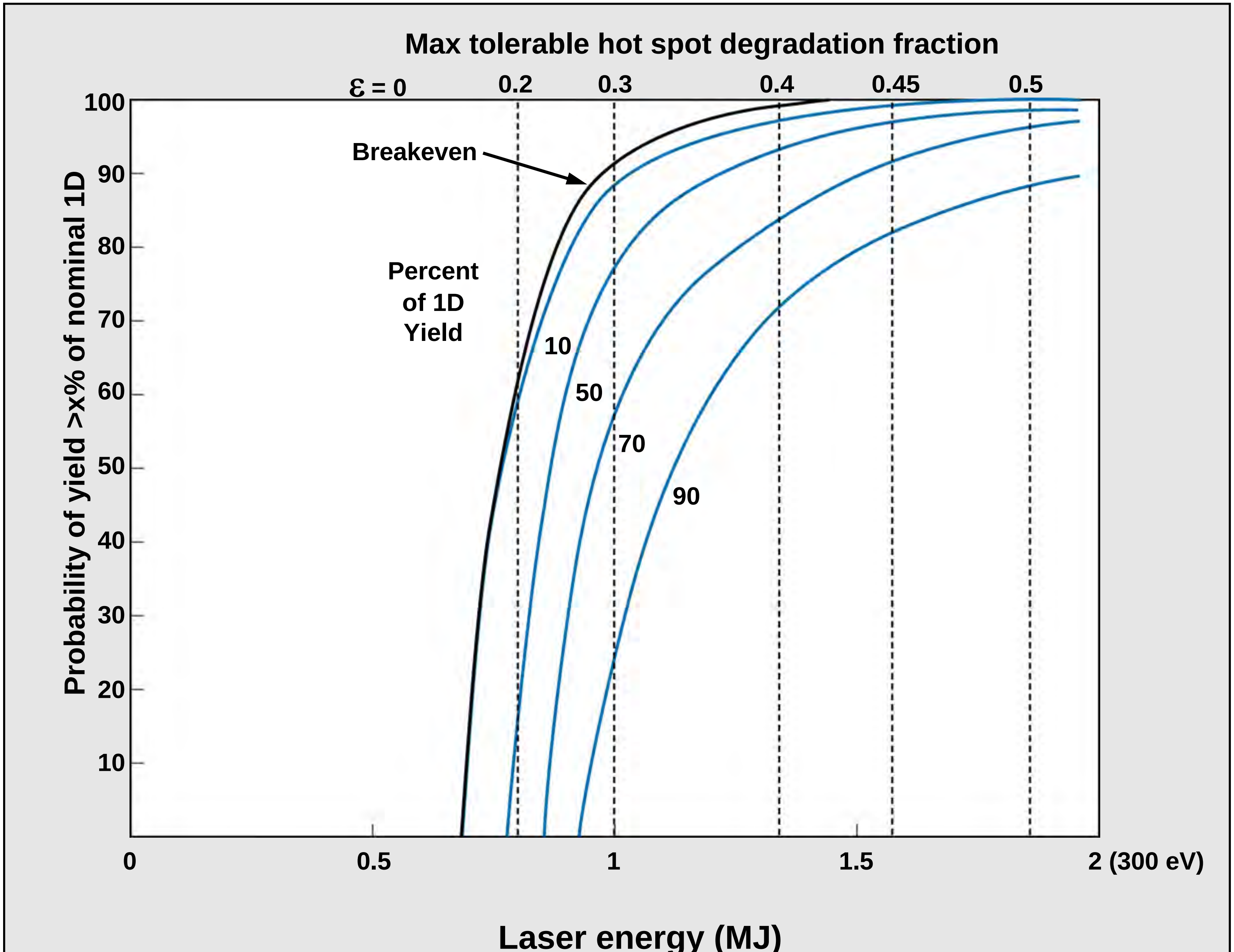
- Low spatial frequency Perturbations
  - — Hohlraum asymmetry
  - — Pointing errors
  - — Power Imbalance
  - — Capsule misplacement in chamber
- High spatial frequency Perturbations
  - — DT ice roughness
  - — Ablator roughness
  - — Ablator microstructure

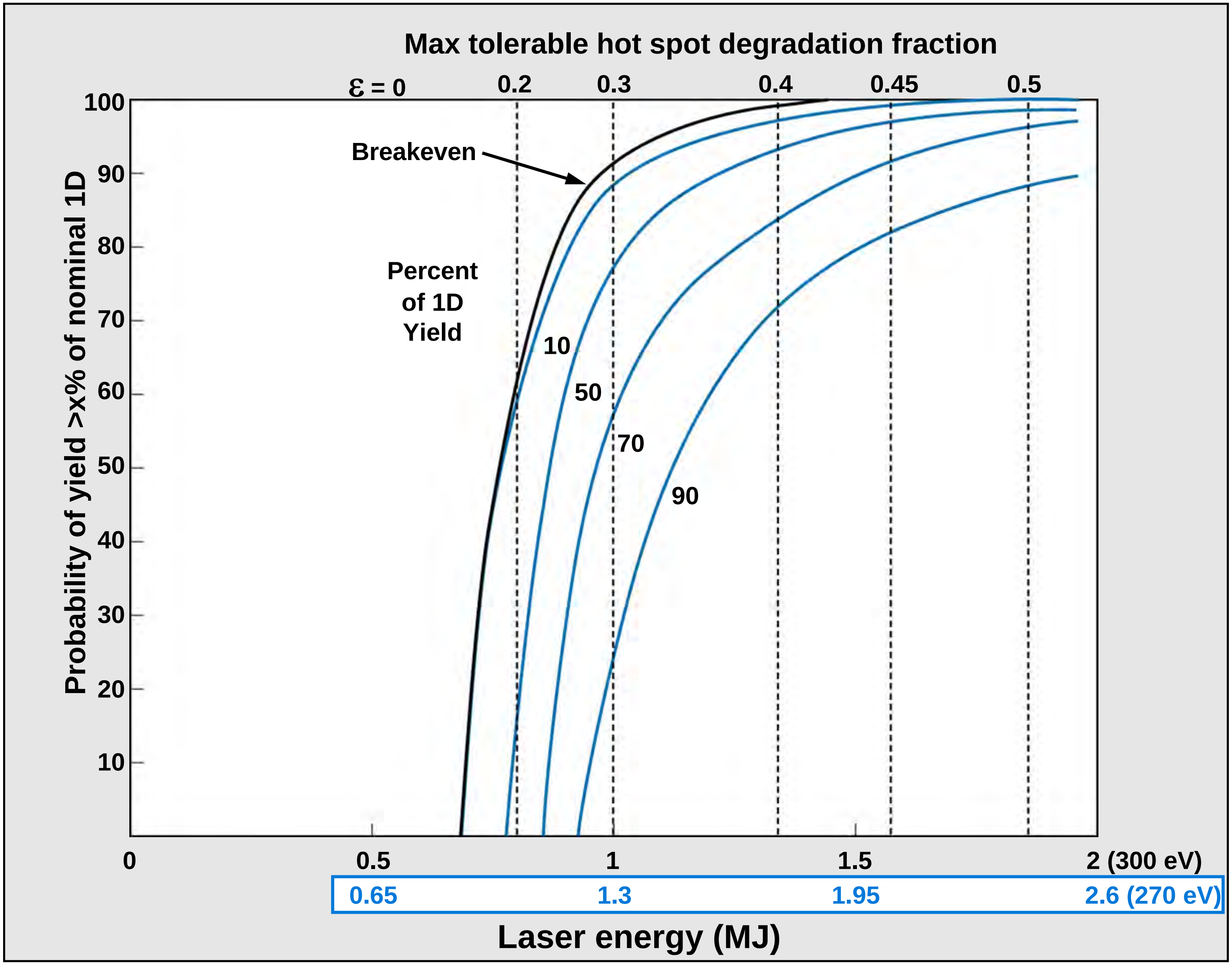
- The hot spot penetration is the fraction of the hot spot radius perturbed by the various sources of error
- The specifications developed for NIF ignition designs result in a hot spot penetration of ~20% for short wavelength modes

When completed, we will have the expected performance curves for capsules at different energies



- Not all effects are included yet — hohlraum asymmetry is the largest effect missing
- Curves at energies other than 1 MJ are estimated from 2D surface roughness sensitivity only

At 270 eV, laser energy for equivalent capsule performance increases by 30%



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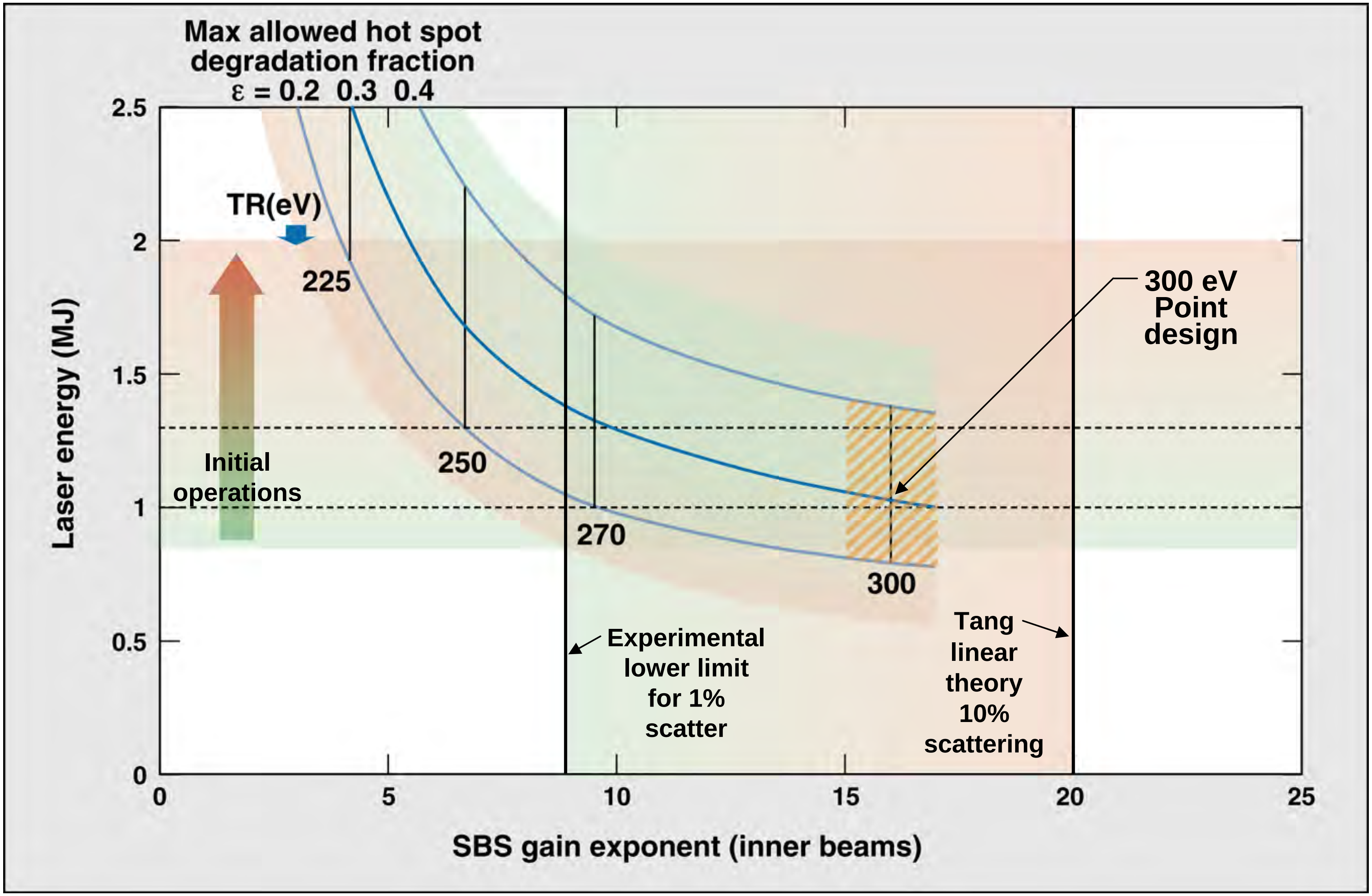
Ignition point design optimization must balance LPI effects, laser performance impacts, and capsule robustness



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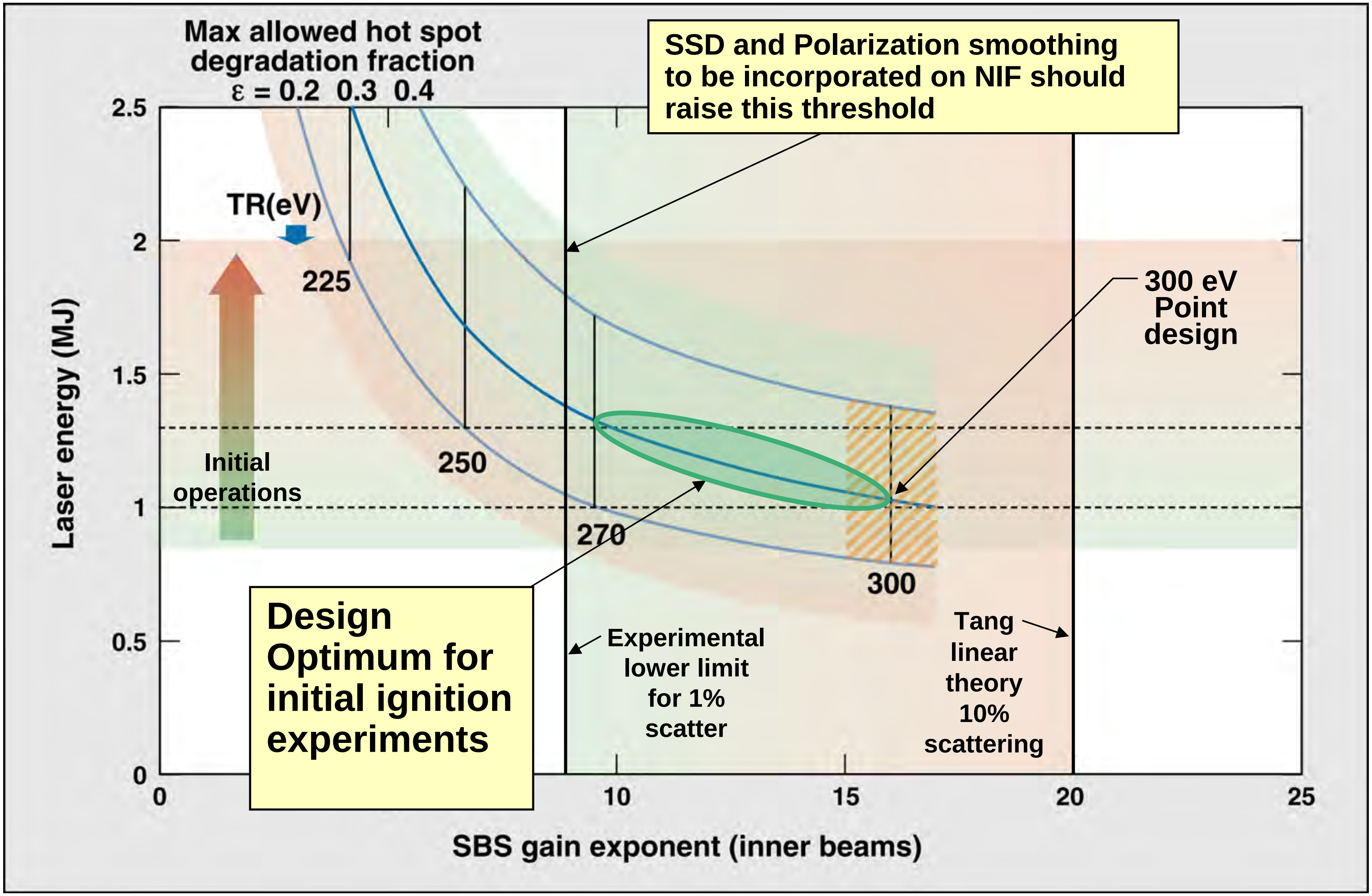

Ignition designs at 300 eV and 270 eV bound the LPI impacts

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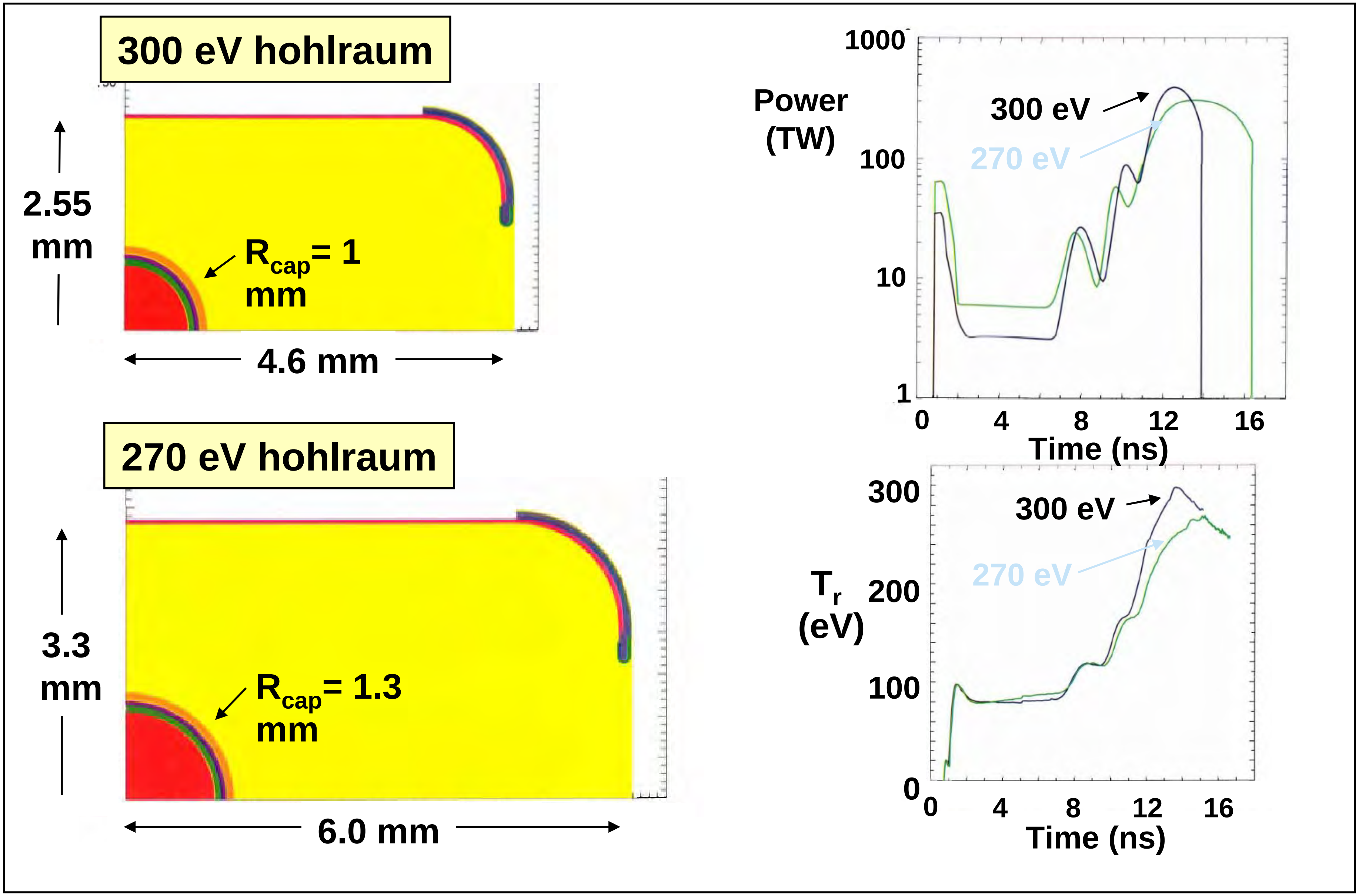

The Ignition experiments plan is organized around Integrated Experiment Teams and their required diagnostics

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Laser Performance	Hohlraum Performance	Capsule Performance	Ignition
• Pulse shape • Power balance • Pointing	• X-ray drive • Symmetry	• Shock timing • Equation of state • Hydro instability	• Point design • Implosion diagnostic signatures

Laser Performance

- SXI - soft x-ray imager for pointing
- SXD - soft x-ray streak for beam timing

Hohlraum Performance

- Dante - thermal x rays
- FFLEX - hard x-rays from high energy electrons
- GXD - gated multi-keV xrays for symmetry

Capsule Performance

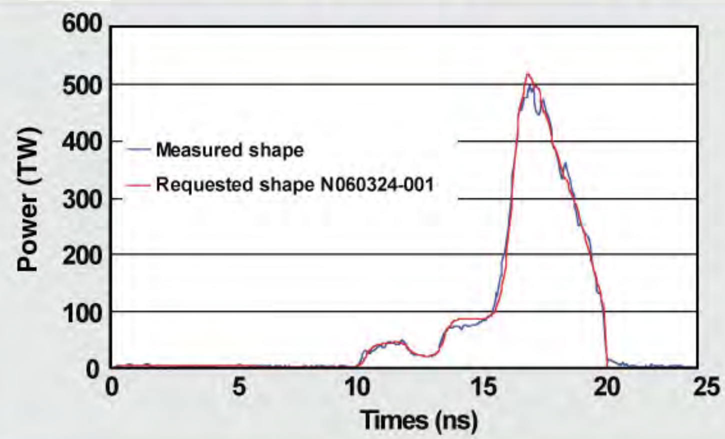
- VISAR - optical interferometer for shock timing
- SOP - streaked optical emission for shock timing
- Cu collection - ablation dynamics
- Proton spectrometer - ablation dynamics
- Streaked x-radiaography – ablation dynamics

Ignition

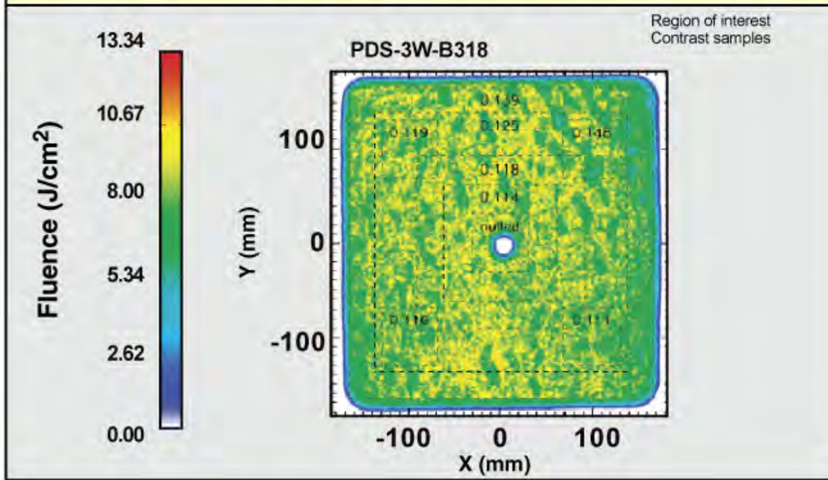
- ARC - Compton scattering for dense fuel imaging
- Neutron imaging
- Gamma bang time
- NTOF - neutron spectroscopy
- MRS - high resolution neutron spectroscopy
- Protex - knock-on protons for yield
- Cu activation for yield
- Carbon activation - tertiary neutrons
- HEXRI - x-ray core

We have demonstrated 1.8 MJ ignition performance: energy, power, pulse shape & beam smoothing simultaneously

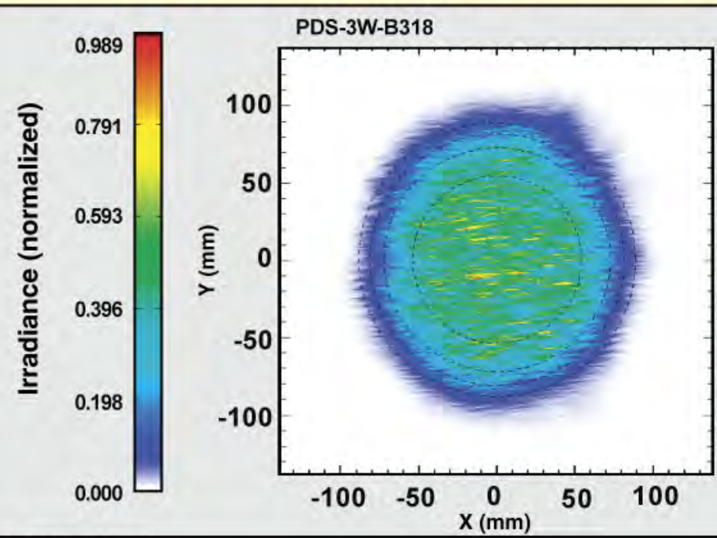
3ω Pulse Shape (500 TW)



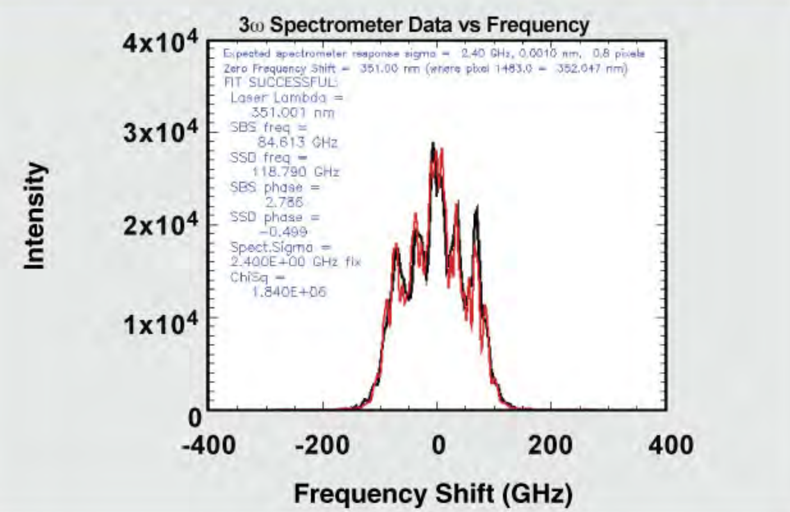
3ω Field Profile (CR = 12.5%)



3ω Focal Spot (1.3 × 1.2 mm²)



3ω SSD Bandwidth (100GHz)



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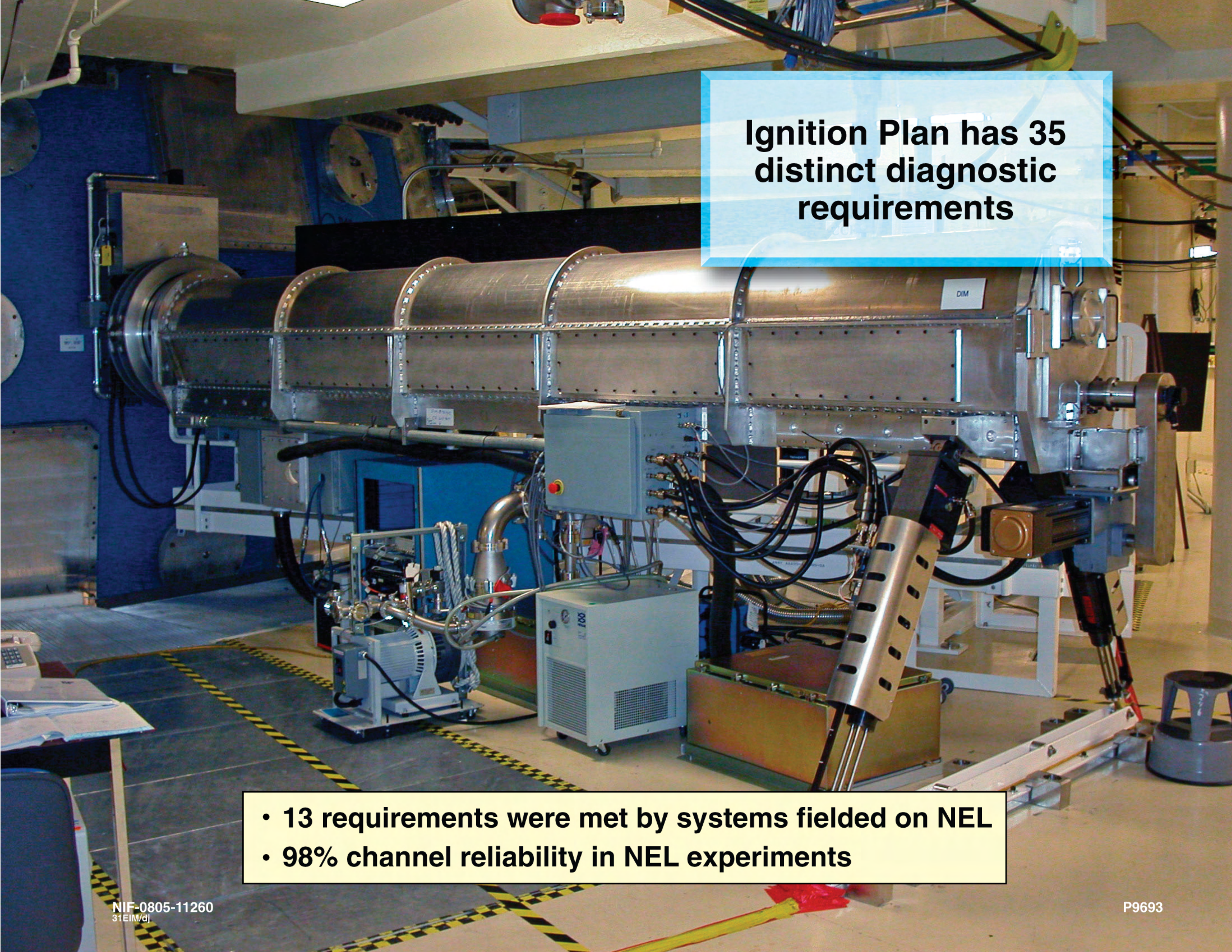
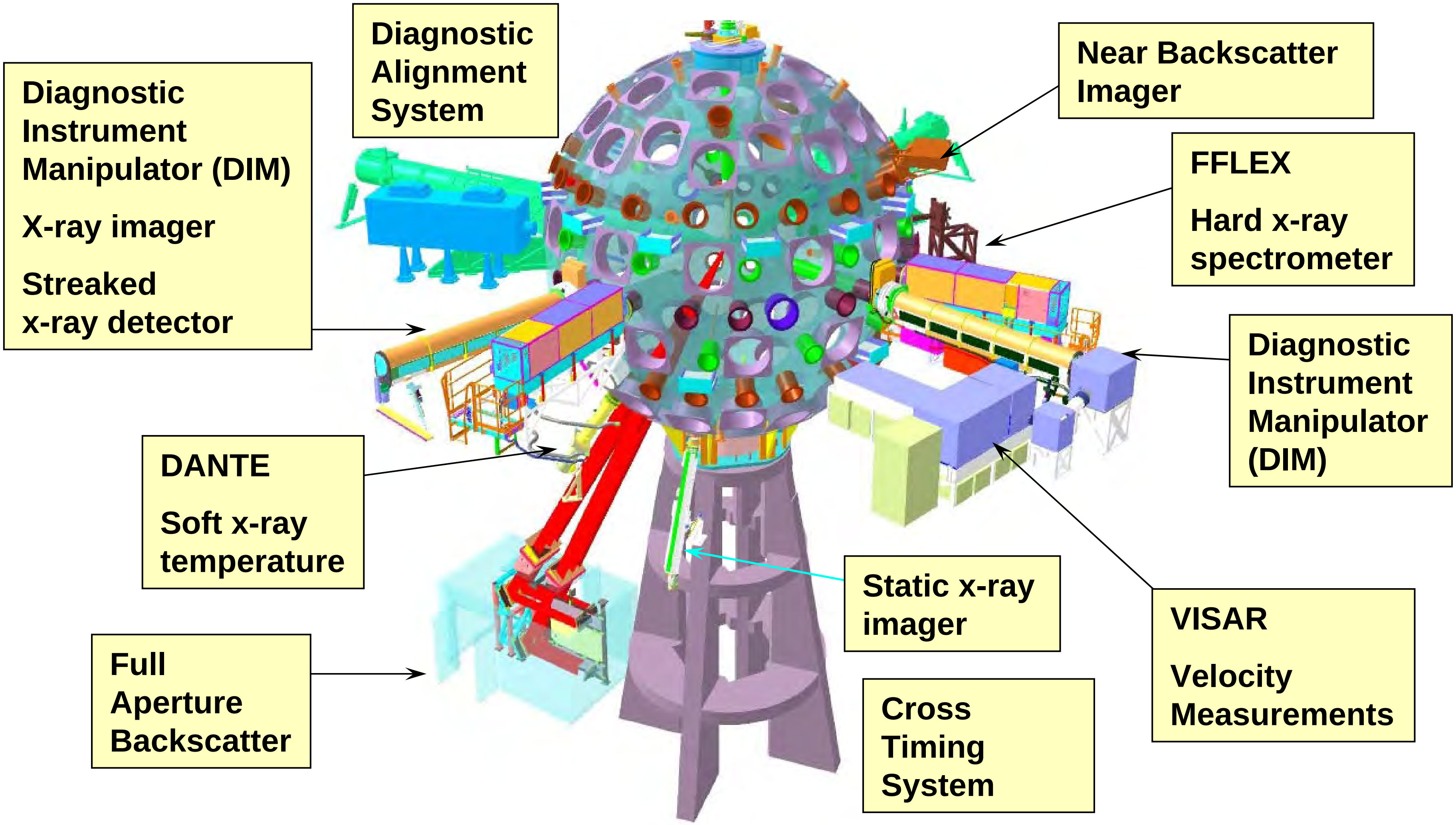
15EIM/sf

Ignition Plan has 35 distinct diagnostic requirements



- 13 requirements were met by systems fielded on NEL
- 98% channel reliability in NEL experiments

We have 30 types of diagnostic systems planned for NIC



We successfully fielded ~ half of all the types of diagnostic systems on NIF

NIF experiments will test important aspects of the point design in 2008 with first implosions in 2009

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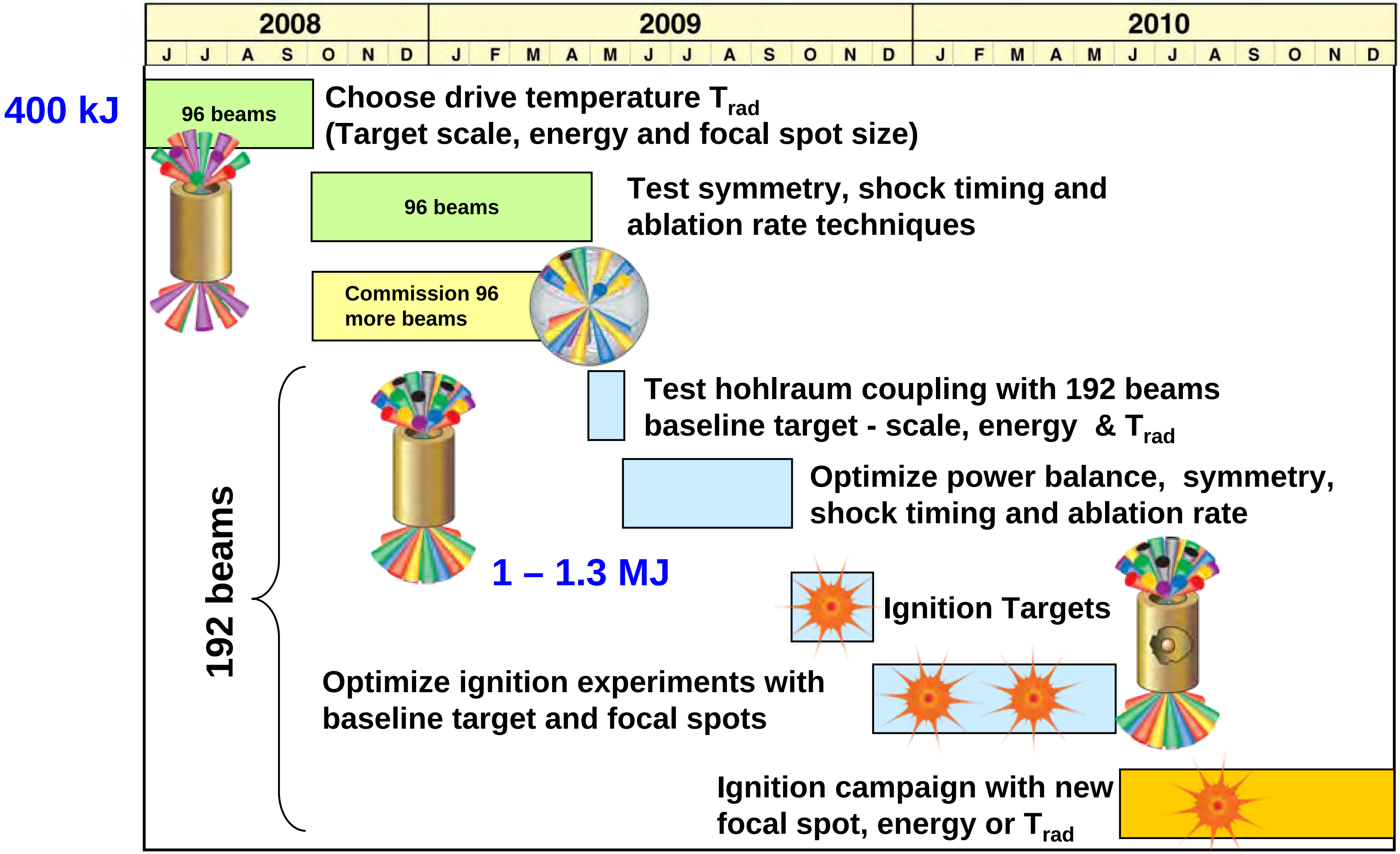
NIC internal goal dates



We are developing an ignition program plan which would enable the first ignition experiments in 2009

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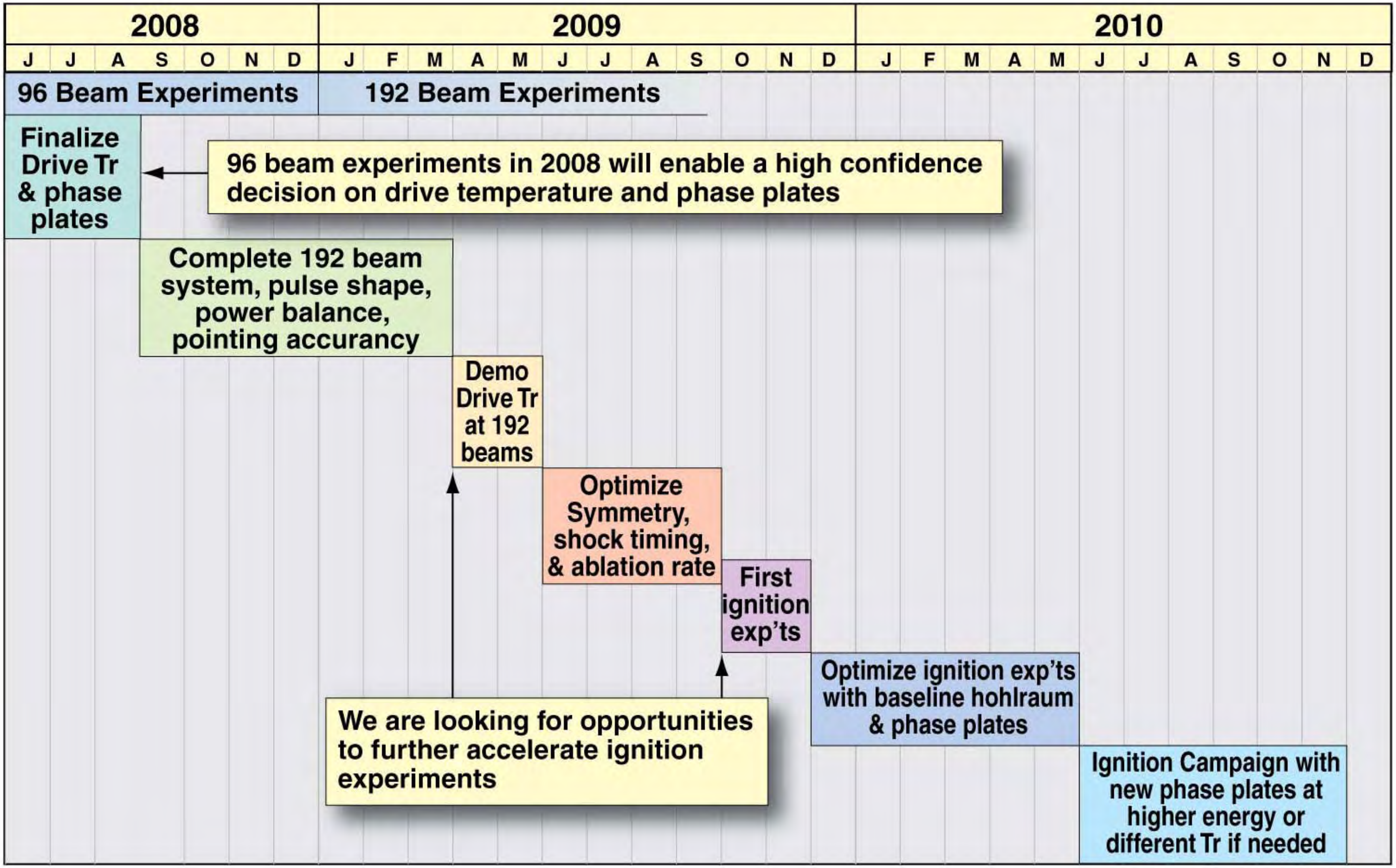

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We emulate ignition hohlraum plasma conditions at 96-beams by scaling the hohlraum to 70% of ignition size

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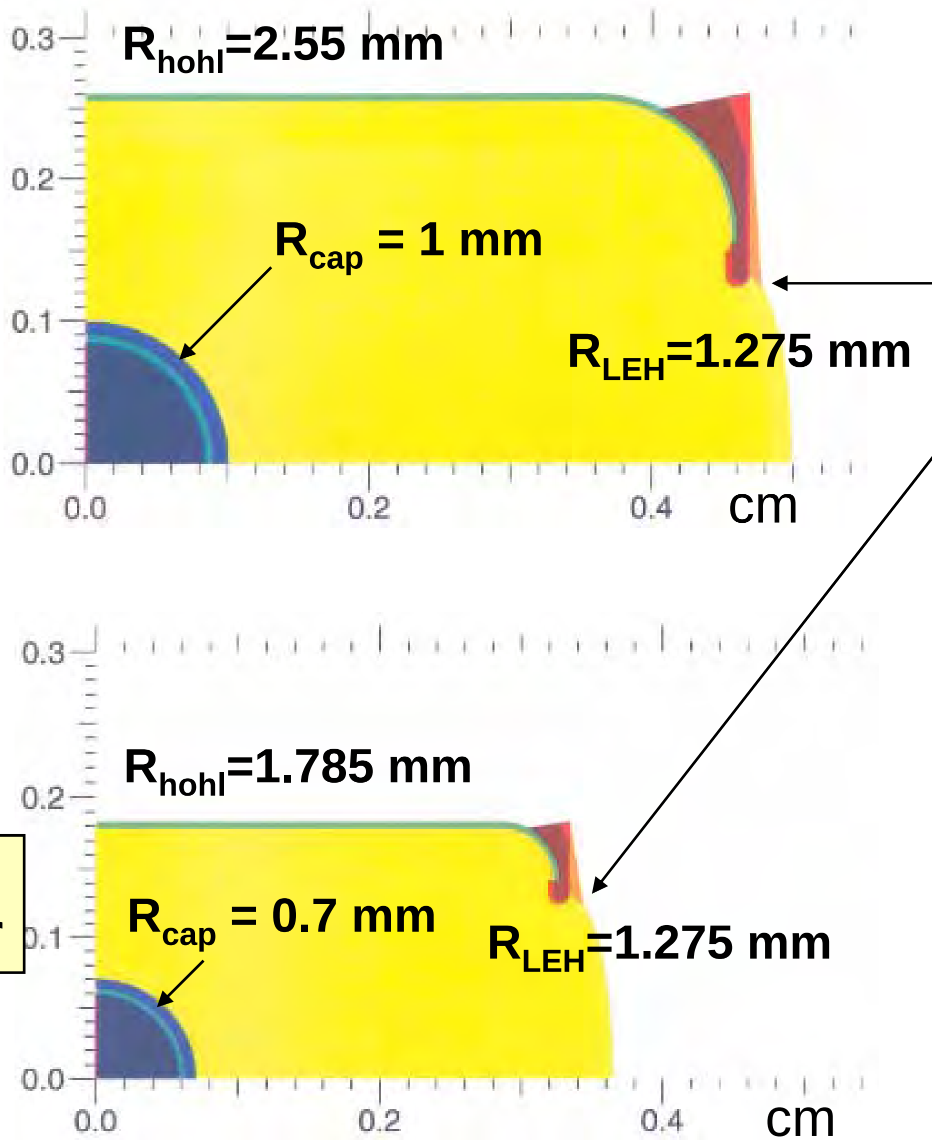
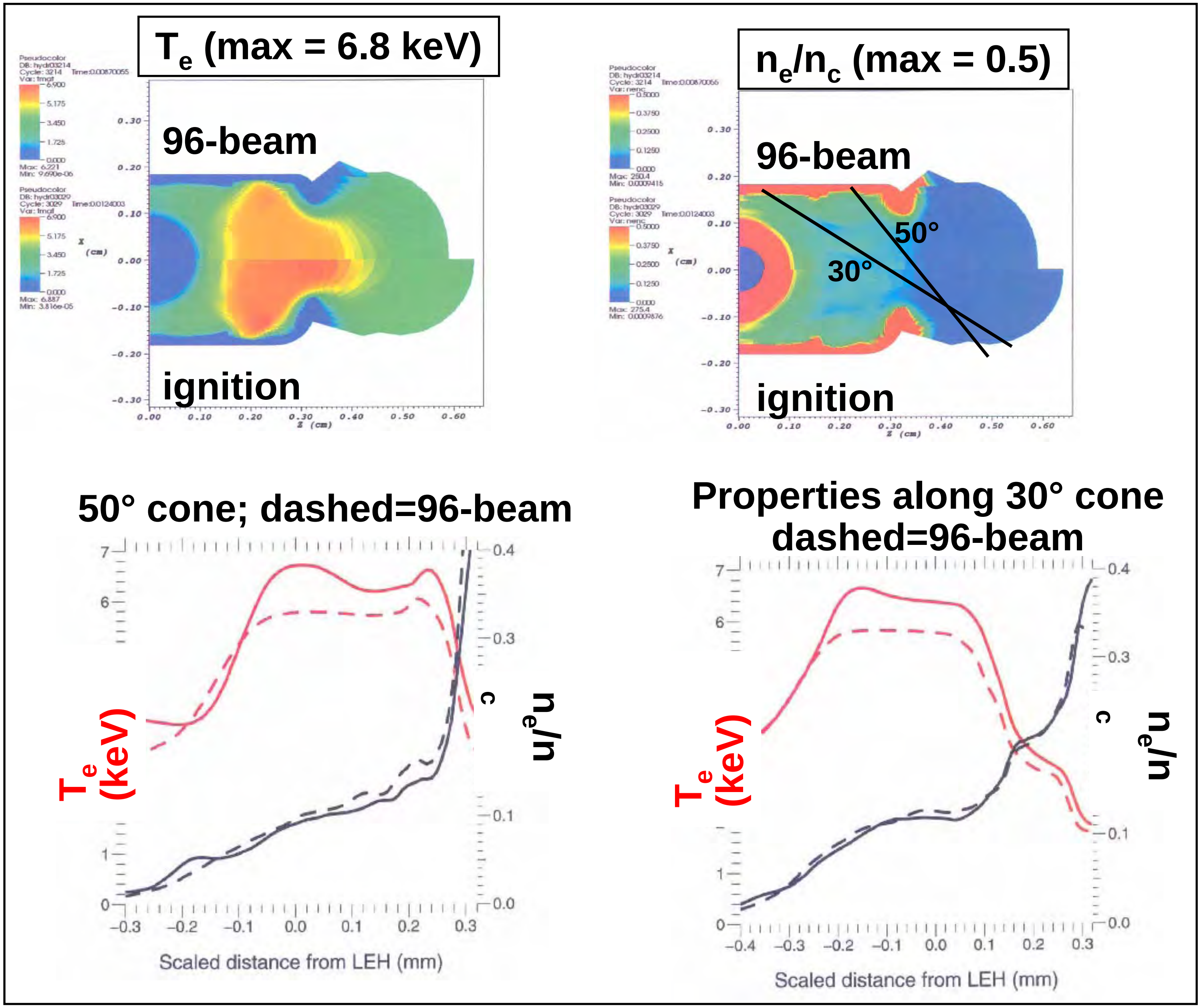
300 eV ignition



96-beam emulator

- **We use full size phase plates so the LEH is not scaled**
- **A 270 eV emulator will use a 1.3 scale hohlraum and 1.3 scale inner phase plates but same outer beam phase plates**

LPI gains, as well as densities and temperatures, are close to those in the ignition design



- At the same laser intensity, the LPI gain for the 96 beam targets is ~70% of that for the igintion target
- The gain will be varied by adjusting the intensity of the interaction beam to determine the LPI operating limits

We will use the 96 beam experiments to pick the operating point for the first ignition experiments

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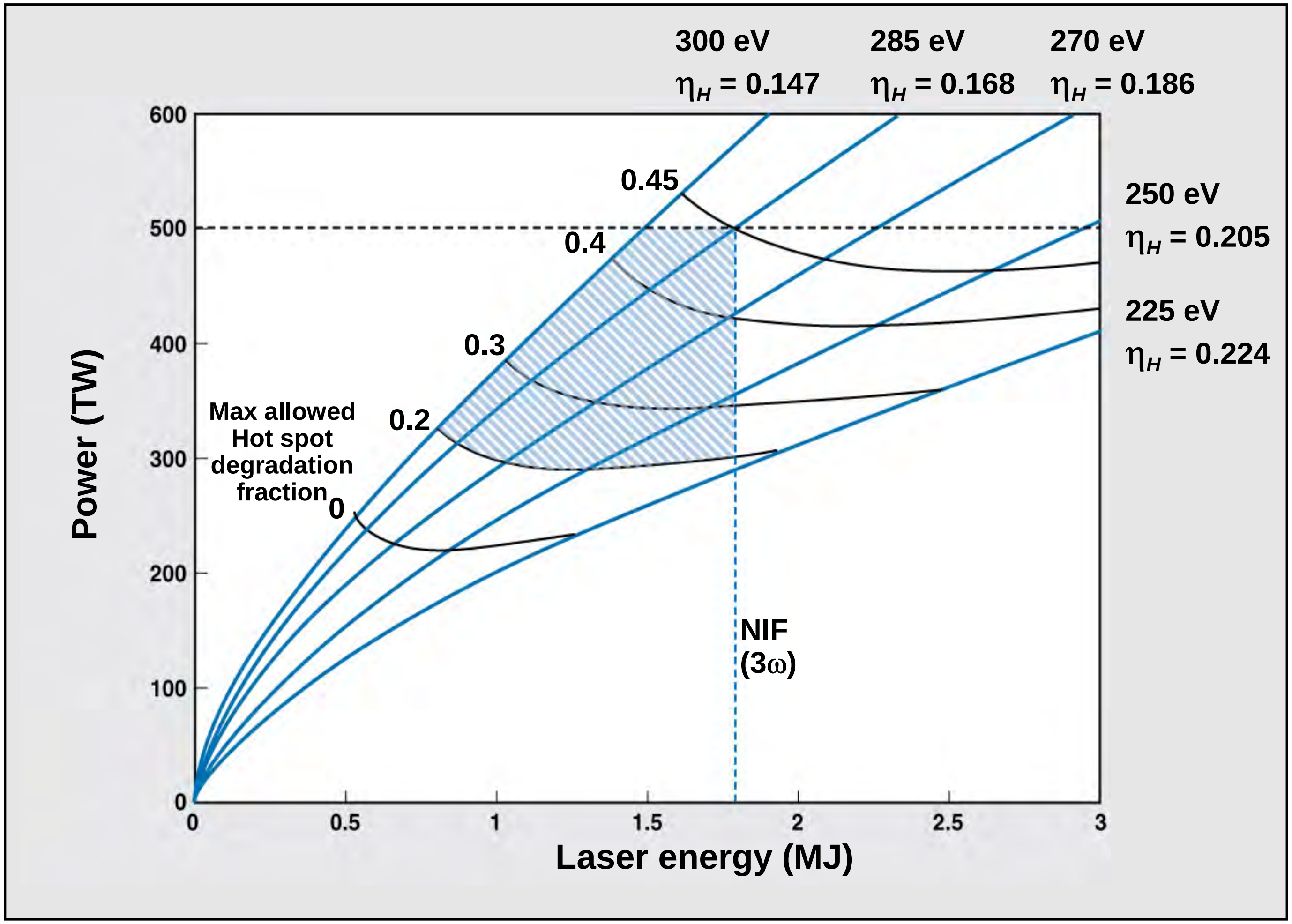
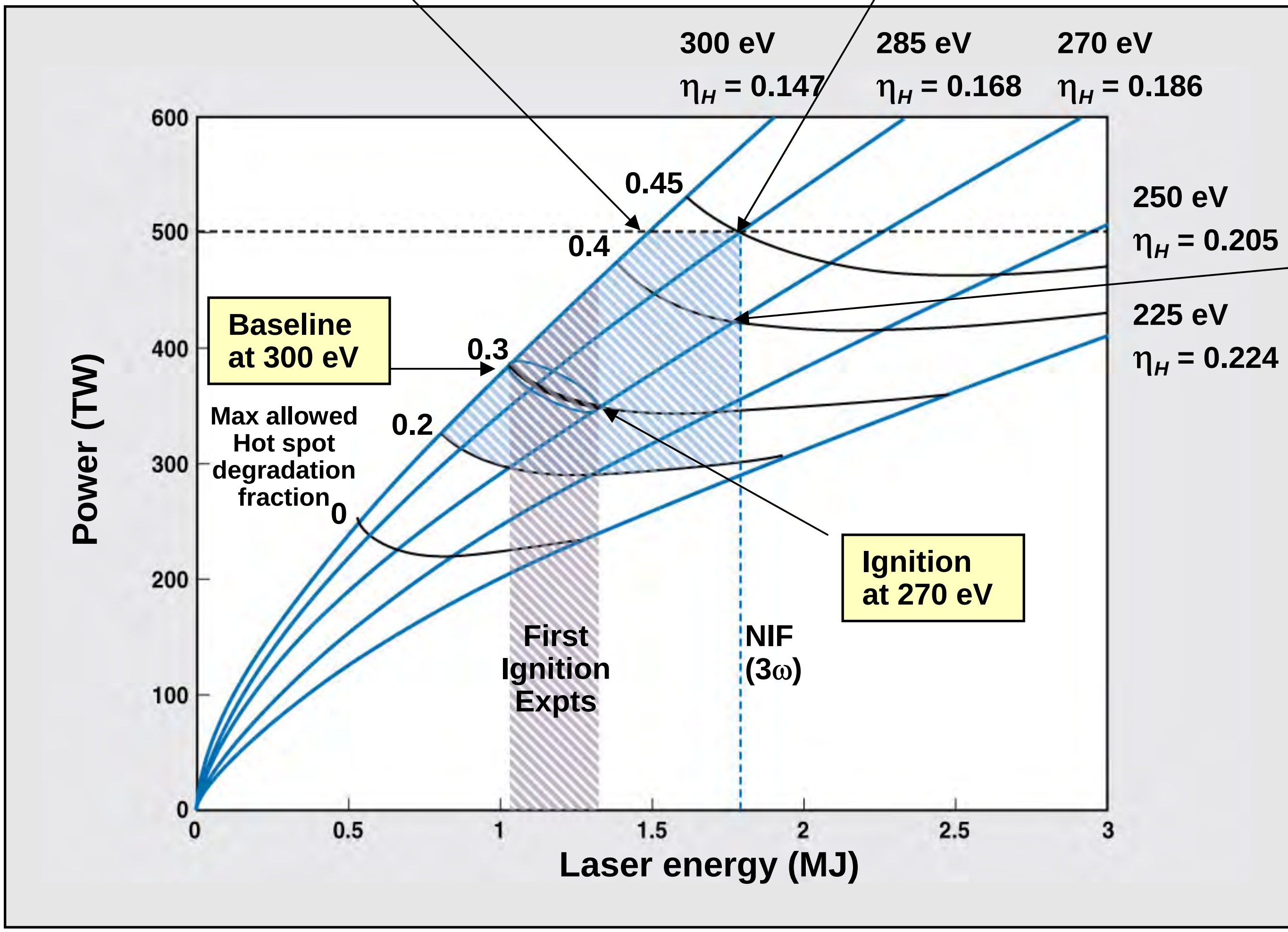


We will use the 96 beam experiments to pick the operating point for the first ignition experiments

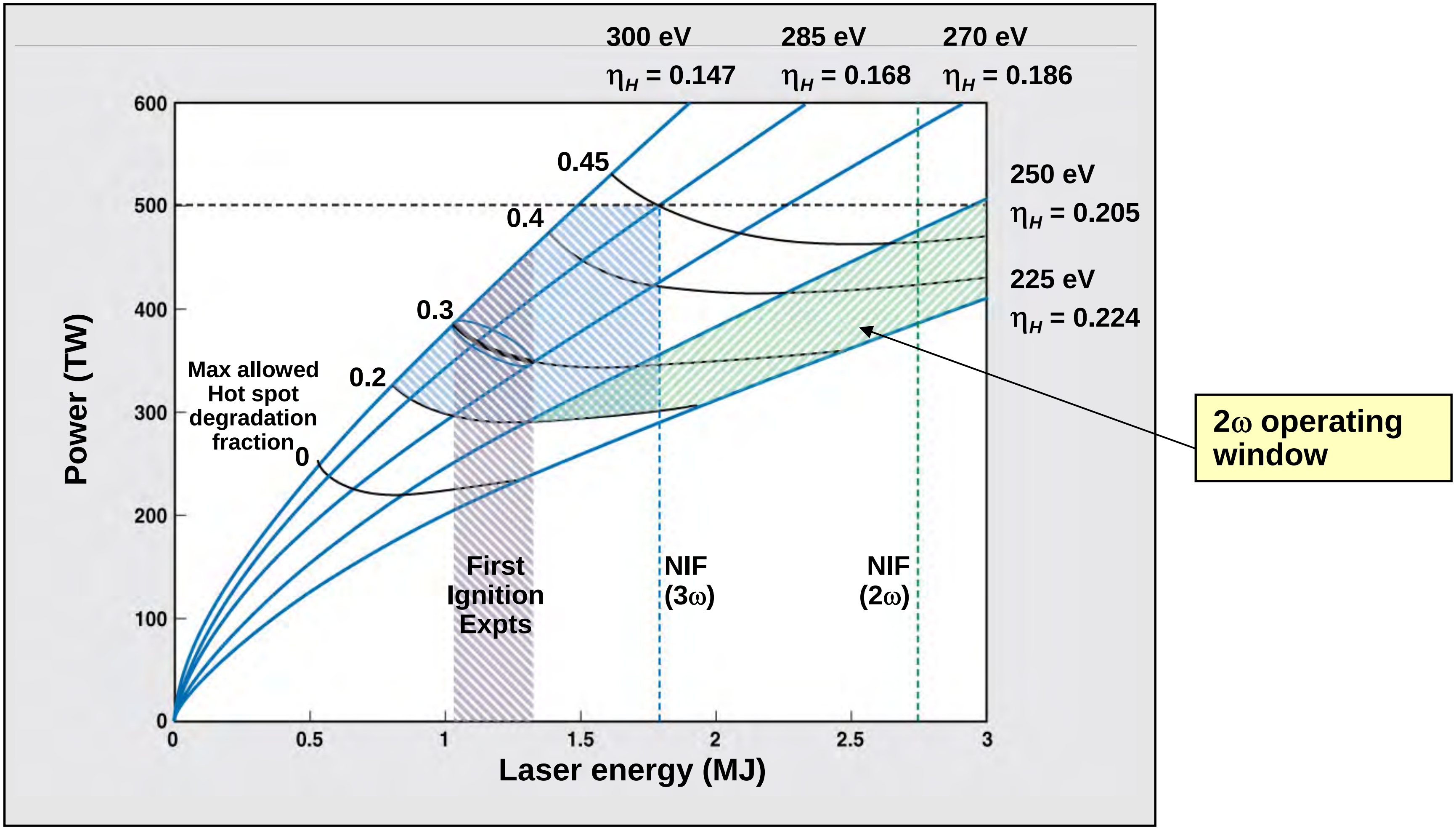
A 300 eV design uses all of NIF's available power before reaching the energy limit - the minimum energy design

Maximum Capsule robustness is achieved with a hohlraum that can utilize both the full power and energy of NIF

A 270 eV design uses all of NIF's energy before reaching the power limit - the minimum LPI design

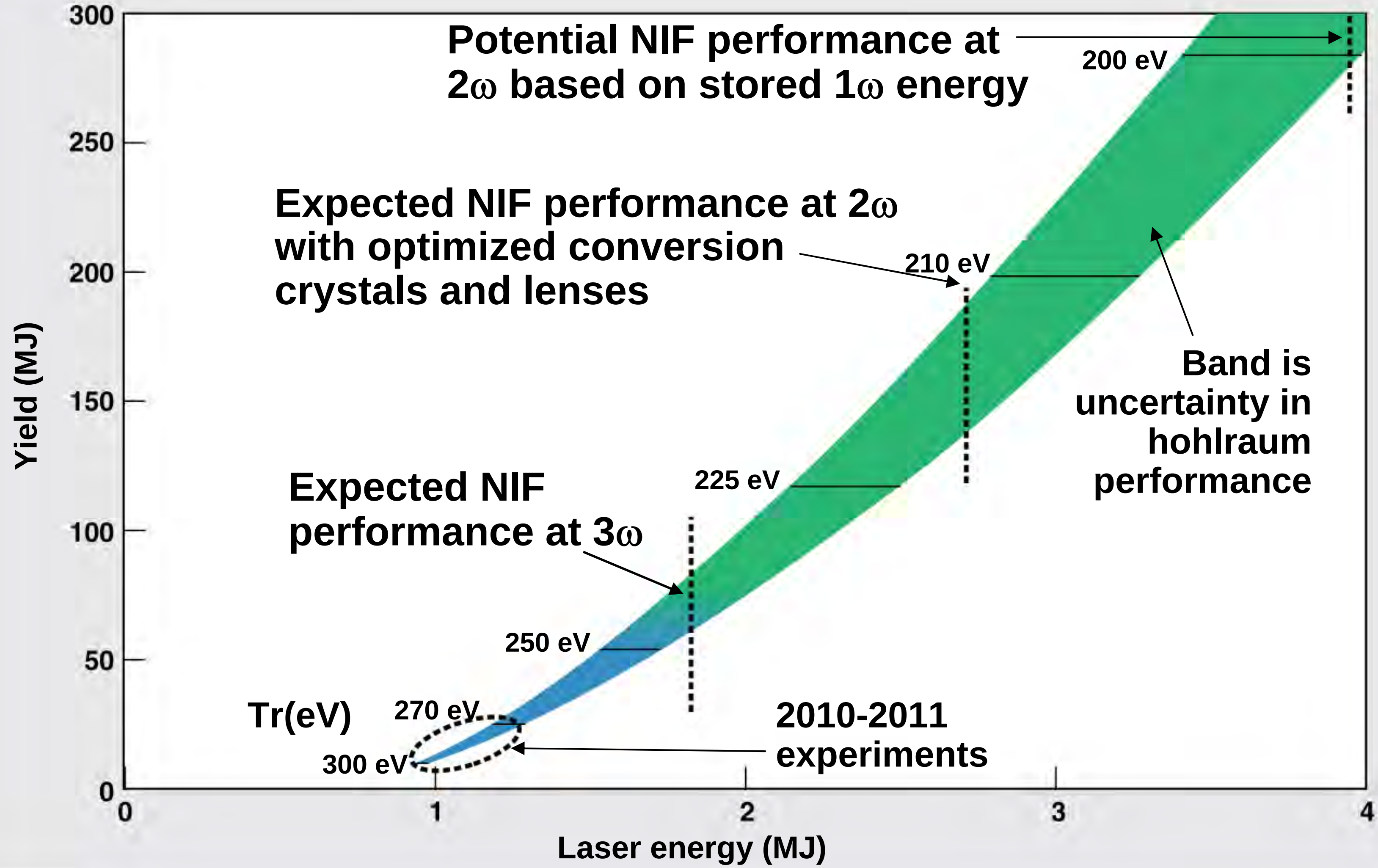


Operating at 2ω provides an opportunity for high yields



Ultimately, yields well in excess of 100 MJ may be possible on NIF

Yields versus laser energy for NIF geometry hohlraums



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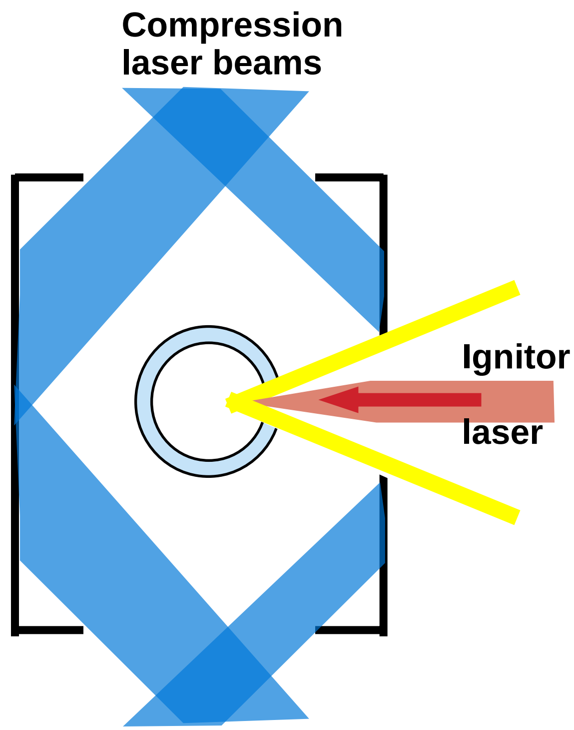
Fast ignition, which separates the fuel compression from ignition, will also be tested on NIF

Fast ignition separates fuel compression from ignition

Step 1: Compression

Compressed fuel density is 1/6 - 1/3 that required for hot-spot ignition



Step 2: Ignition

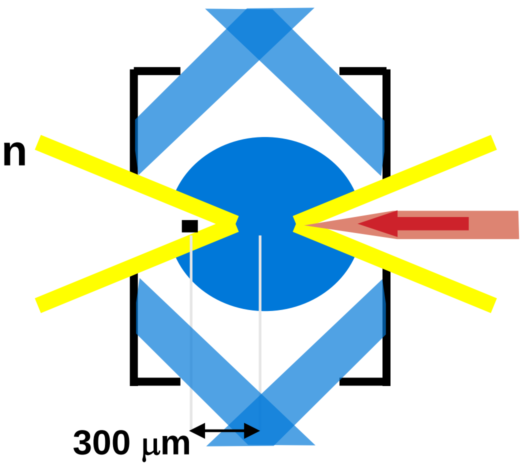
Ignition laser generates hot electrons that deposit their energy initiating a burn wave

- Symmetry requirements relaxed
- Flexible non-spherical configurations
- May allow longer wavelength driver

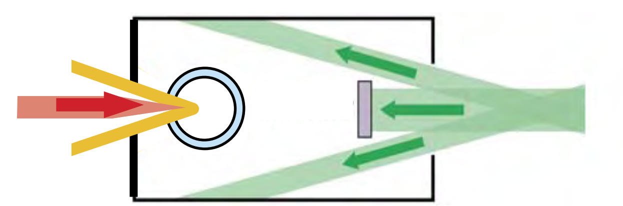
Overall laser energy requirements for Fast Ignition are reduced compared with Hot Spot Ignition → Higher Gain

Non-spherical ignition geometries open up many applications of ignition

- **High Energy Density Science**
  - Test objects can be driven to extreme conditions by well-characterized fluxes
  - Cone geometry allows access to highest intensity neutron and ion flux densities



- **Fundamental Physics Research**
  - Precision and flexibility in placement of samples
- **Inertial Fusion Energy**
  - Low solid-angle, two-sided illumination geometry compatible with thick liquid wall target chambers



- **Recruitment and Retention**
  - Fast Ignition is a “magnet” for attracting the next generation of scientists and scientific leaders

ARC (Advanced Radiographic Capability) is being implemented on NIF as a major diagnostic for NIC

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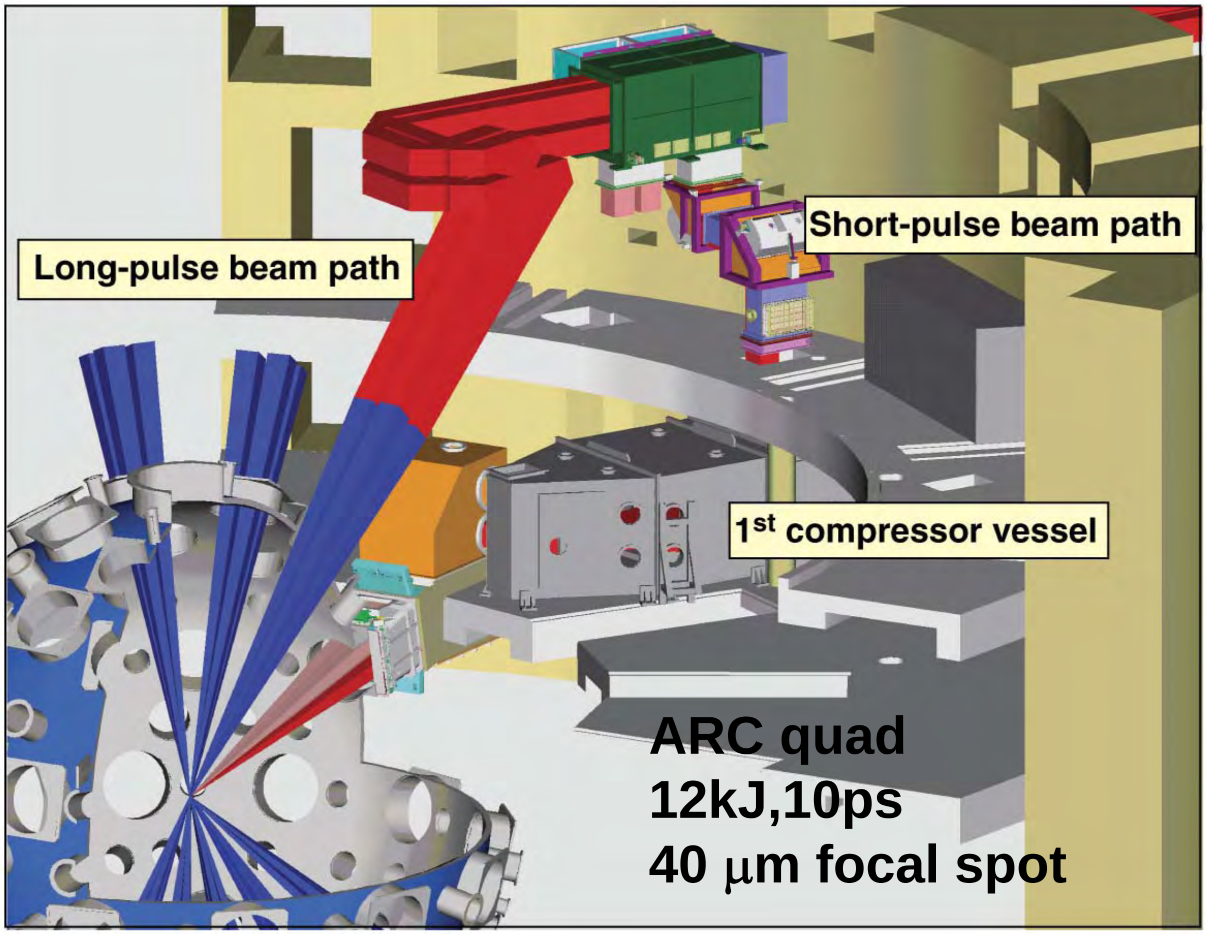

- A "Quad" of NIF beams is compressed to deliver a 1-10 ps pulse
- Uses include backlighter for dense cold fuel in ignition targets and a variety of high optical depth HEDP targets
- Up to 5 short pulse quads could be deployed on NIF for fast ignition

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